Welcome to Fermilab

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Associate Laboratory Director for Computational Science and AI
May 23, 2024

Welcome to Fermilab

Ask questions!

Fermilab at a Glance

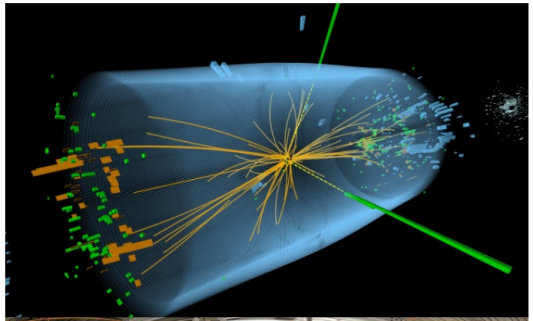
- America's particle physics and accelerator laboratory
- Operates the largest US particle accelerator complex
- ~2,100 staff and ~$750M/year budget
- 6,800 acres of federal land
- Facilities used by >4,000 scientists from >50 countries

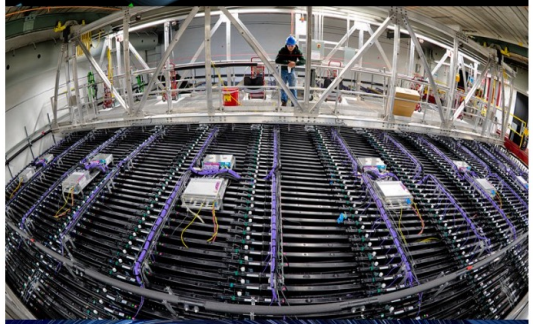
As we move into the next 50 years, our vision remains to solve the mysteries of matter, energy, space, and time for the benefit of all.

Why We Are Here: High Energy Physics

From the Department of Energy

High Energy Physics (HEP) explores what the world is made of and how it works at the smallest and largest scales, seeking new discoveries from the tiniest particles to the outer reaches of space.





Energy Frontier

Researchers at the Energy Frontier use the world's largest and highest energy particle accelerator to recreate the universe as it was a billionth of a second after the Big Bang.

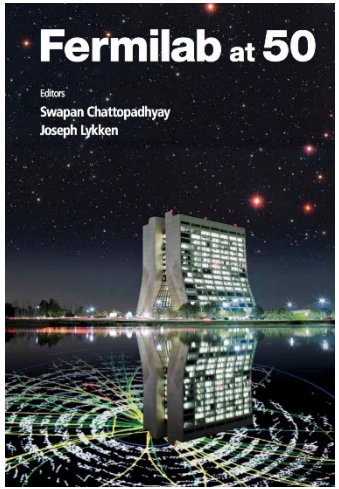
Intensity Frontier

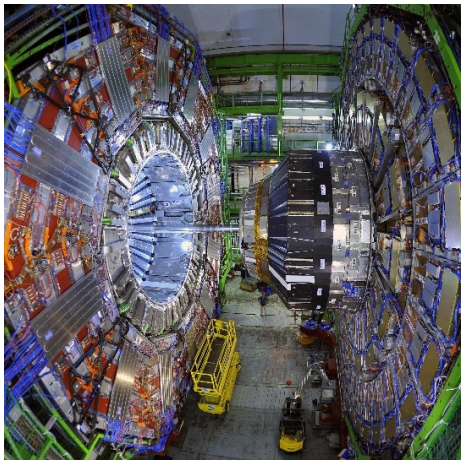
Researchers at the Intensity Frontier investigate some of the rarest particle interactions in nature and subtle effects that require large data sets to observe and measure.

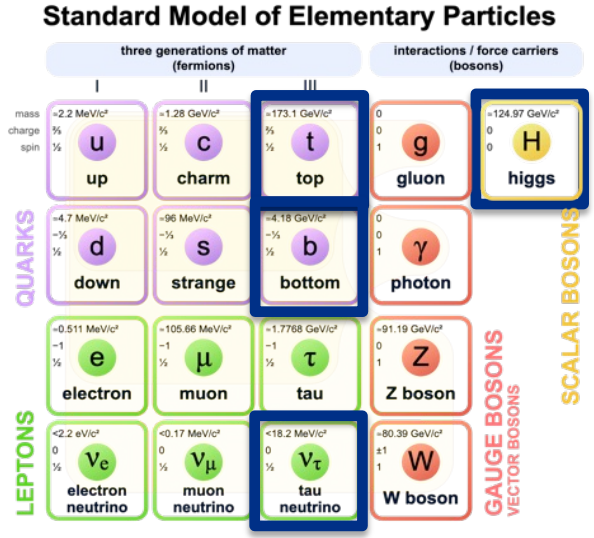
Cosmic Frontier

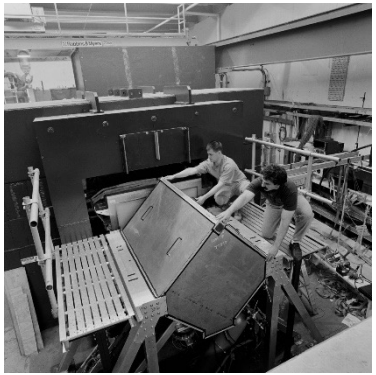
Researchers at the Cosmic Frontier use naturally occurring cosmic particles and phenomena to reveal the nature of dark matter, cosmic acceleration, and more.

50+ Years of Discovery









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FNAL is an international facility

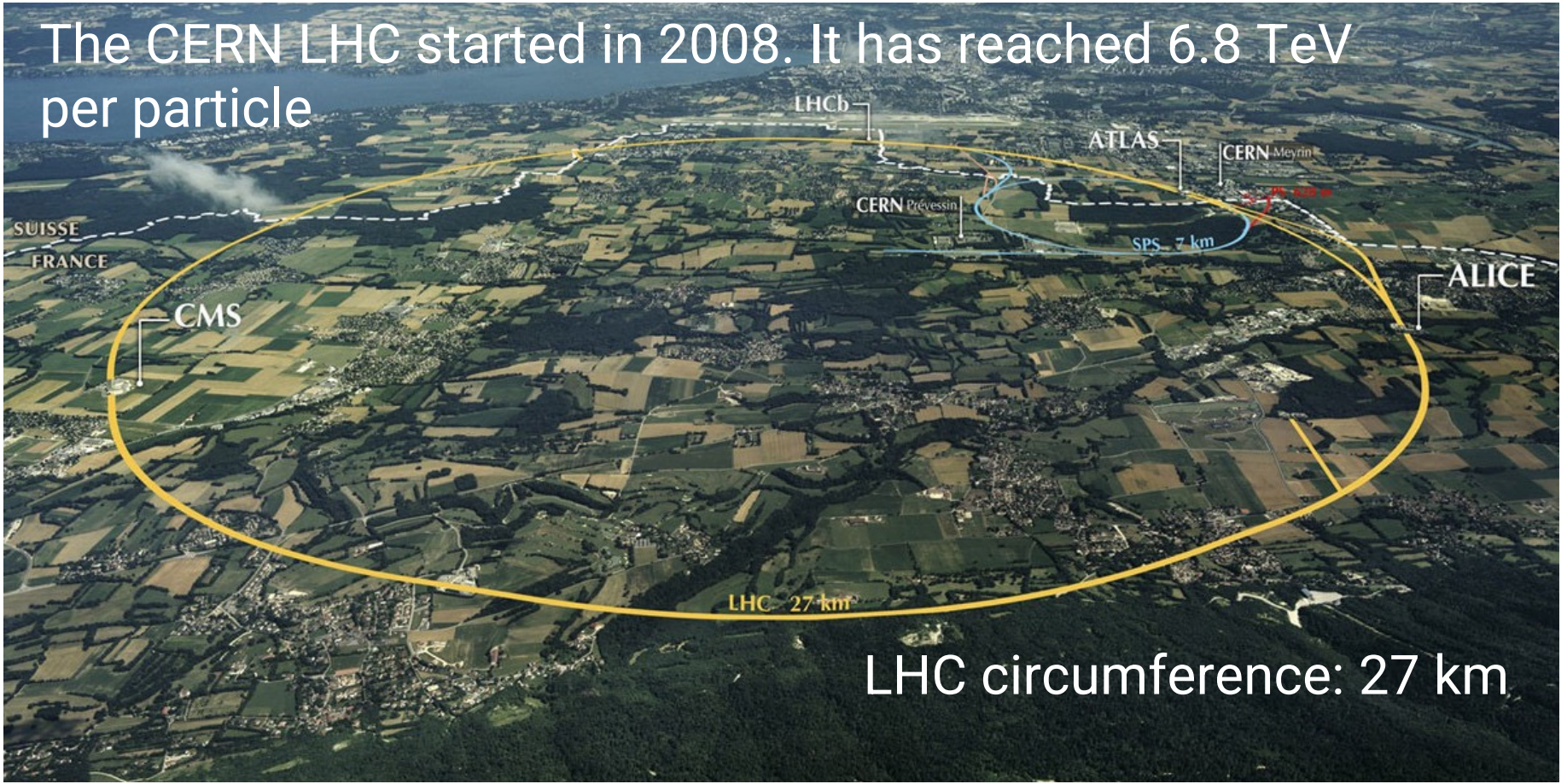
Next Generation facilities must be international to succeed!

"Now more than ever, particle physics is an international, even global, endeavor"
HEPAP P5 report, 2023

"Continue support for and actively seek engagement with international collaborations and partnerships of all sizes"
DOE International Benchmarking Report, 2023


Tevatron
circumference: 6.3 km
2π km!
Main Injector
circumference
3.3 km
At 1 TeV per particle, the Tevatron was the world's highest energy particle accelerator until 2008

The CERN LHC started in 2008. It has reached 6.8 TeV per particle



LHC circumference: 27 km

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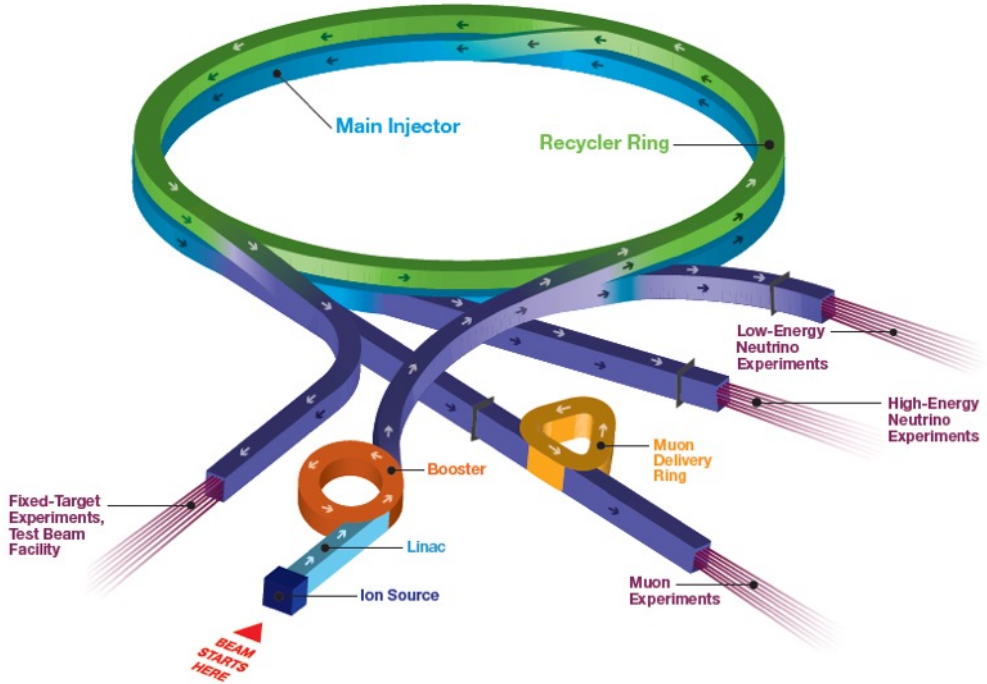
Intensity Frontier

Neutrinos

Muons

AD: Fermilab Accelerator Complex – world-leading proton beam facility



Beams to Booster Neutrino beam, NuMI, muon campus, Test beams (MTA and 120 GeV), fixed target (spinquest)

120 GeV beam power – 0.895 MW

Over 5 years power increased by 30% while beam loss reduced by factor 2

Operation with uptime of ~80%

Continue to ramp up MI power through cycle time reduction

Looking ahead to 20-year plan for modernization of the complex (P5 report)

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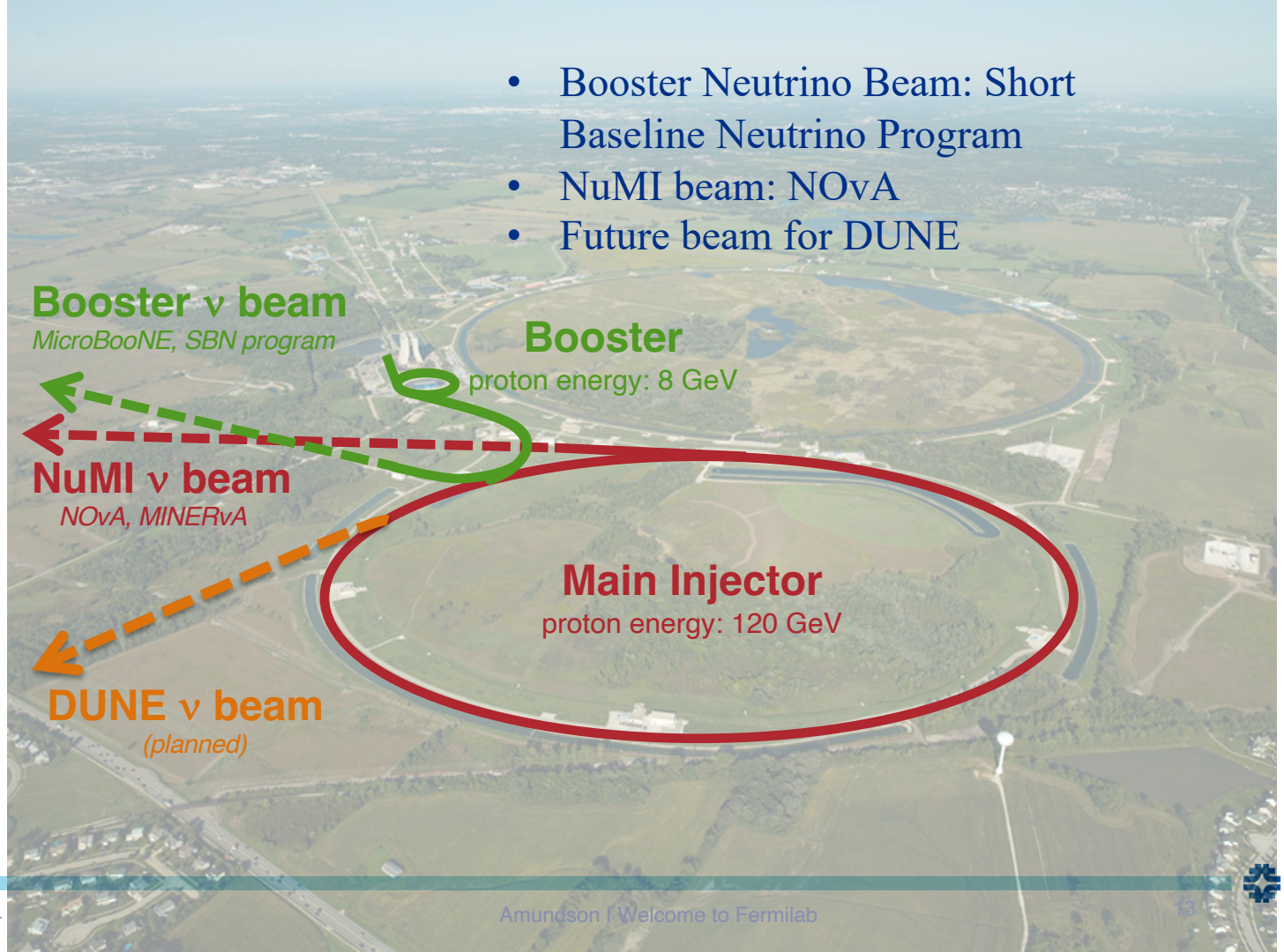
- Booster Neutrino Beam: Short Baseline Neutrino Program
- NuMI beam: NOvA
- Future beam for DUNE



The international PIP-II accelerator project

Neutrino Science: NOvA

- Doubled (1.96x) FHC(v) dataset at the end of FY23 accelerator run. Returning to RHC (anti-v) running in FY24
- 2024

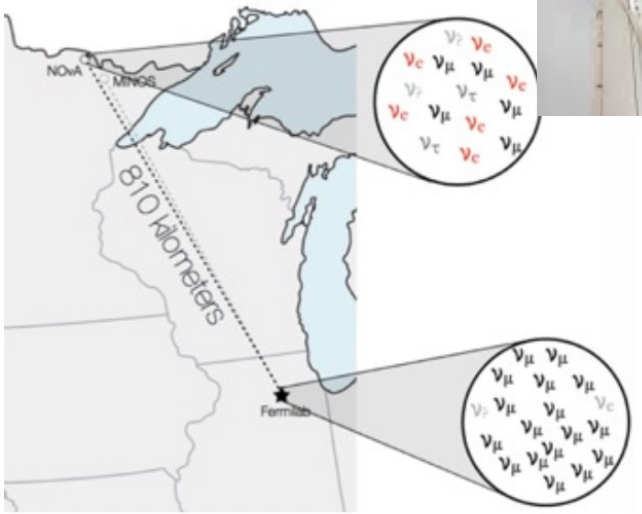
  New 3-flavor oscillation results with double the FHC data.

  Results from the joint fit with T2K

  New cross section measurements

  New BSM search

Long baseline neutrino oscillation experiment



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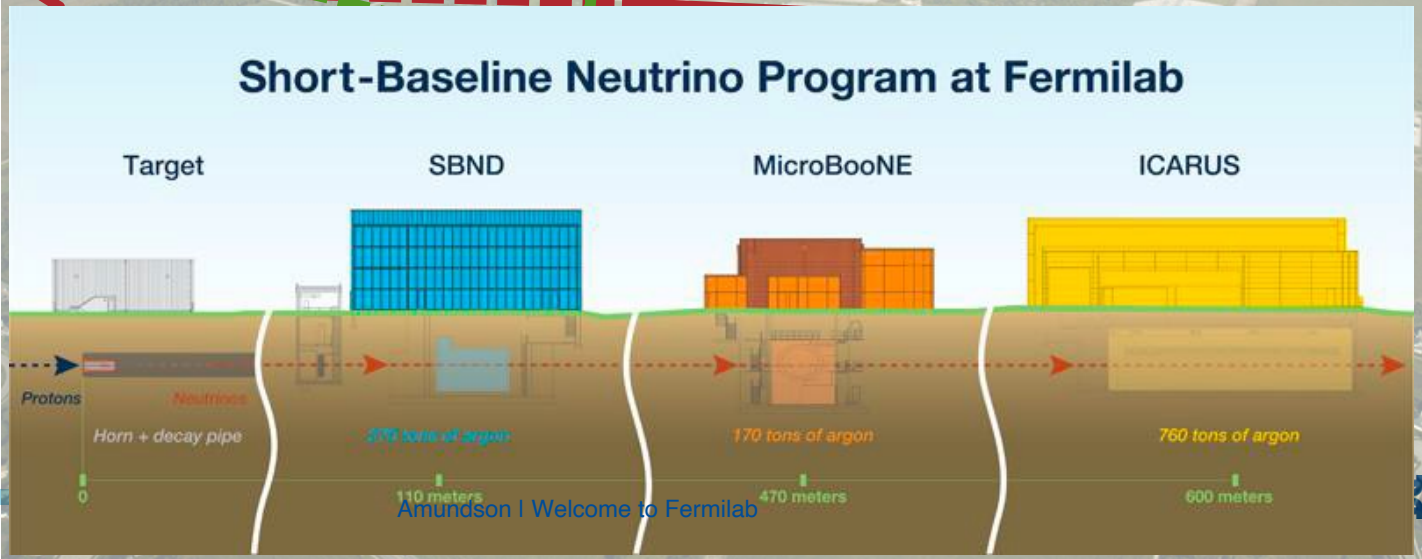
Neutrinos at Fermilab

SBN program: Series of detectors addressing anomalies at short baseline and developing technology for DUNE

Booster ν beam
MicroBooNE, SBN program

Booster
proton energy: 8 GeV



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Neutrino Science: SBN Operations start in 2024

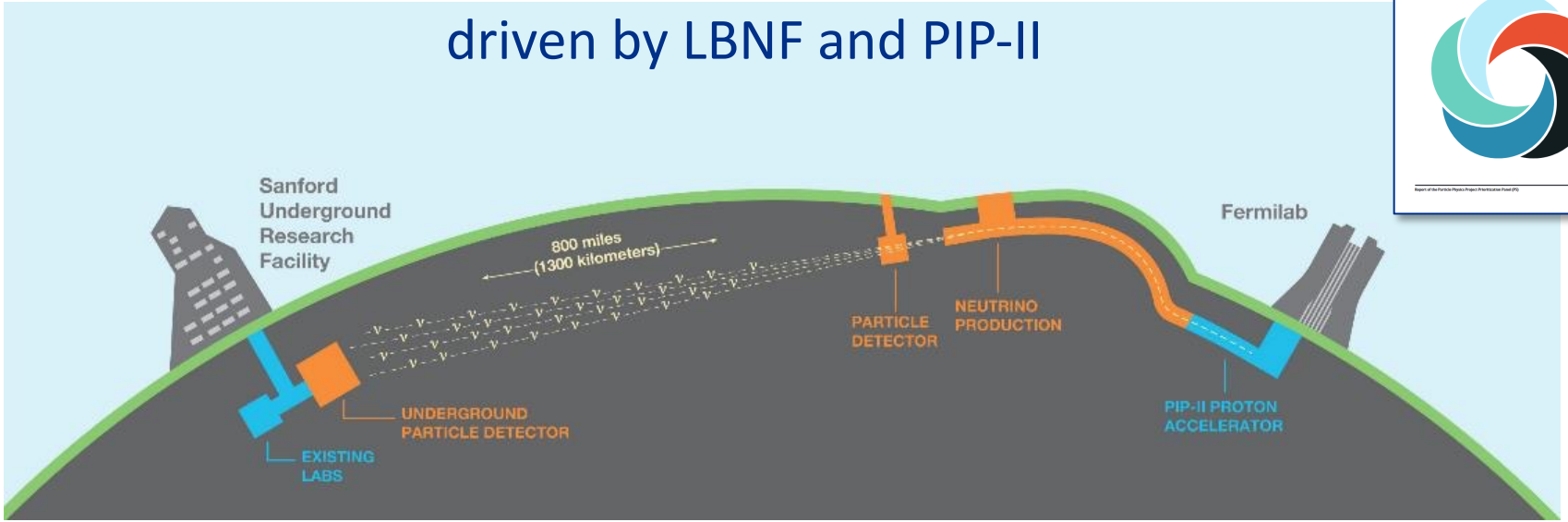
- MicroBooNE continues to publish papers (>60 peer reviewed papers to date)
- ICARUS taking data and looking ahead to first results
- SBND commissioning now!
  - Looking ahead to first physics data this year

Detector rigging into the cryostat

CRT north wall installation

Cabling and cryogenic connections

“Best in Class” neutrino experiment driven by LBNF and PIP-II



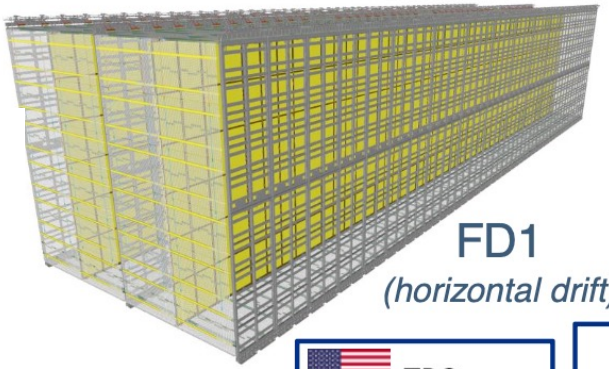
Origin of matter. Investigate leptonic CP violation. Are neutrinos the reason the universe is made of matter?

Neutron star and black hole formation. Ability to observe neutrinos from supernovae events and perhaps watch formation of black holes in real time.

Unification of forces. Investigate nucleon decay, advance unified theory of energy and matter.

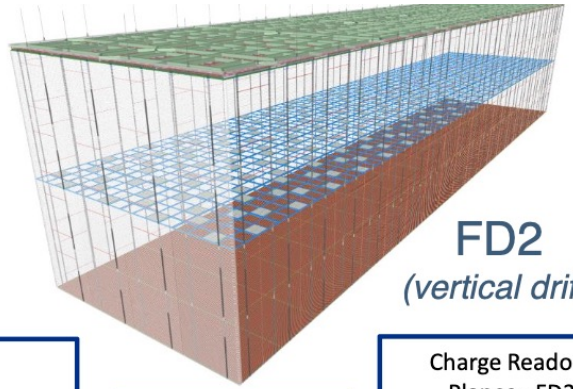
The LBNF/DUNE project will be the first internationally conceived, constructed, and operated mega-science project hosted by the Department of Energy in the United States” – DOE

The DUNE Far Detectors – A Model of International Partnership



FD1
(horizontal drift)

High Voltage
FD1, FD2



FD2
(vertical drift)

Anode Plane
Assemblies - FD1

TPC
Electronics
FD1, FD2-B

Photon Detection
FD1, FD2

Data Acquisition
FD1, FD2

Charge Readout
Planes - FD2

CALCI
FD1, FD2

Brookhaven
National Laboratory

BERKELEY LAB

Argonne
NATIONAL LABORATORY

Fermilab

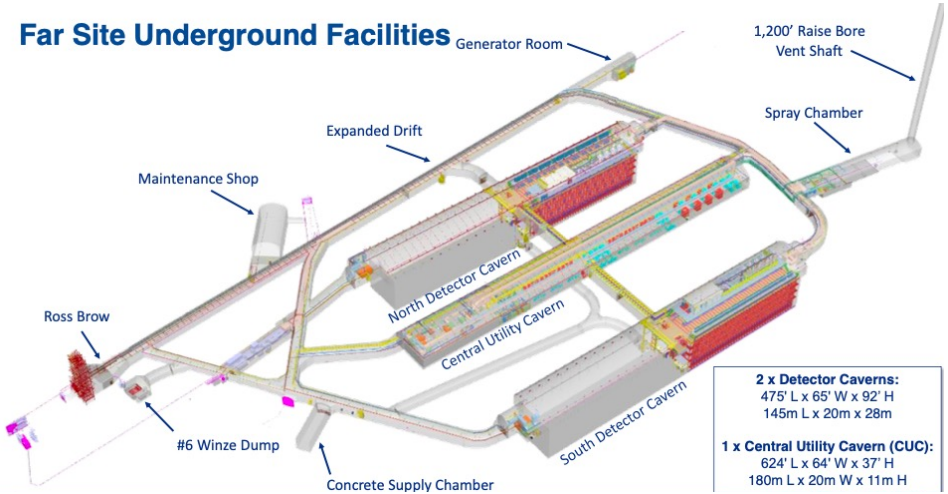
Los Alamos
NATIONAL LABORATORY

Electronics
FD2-T

+ many Universities

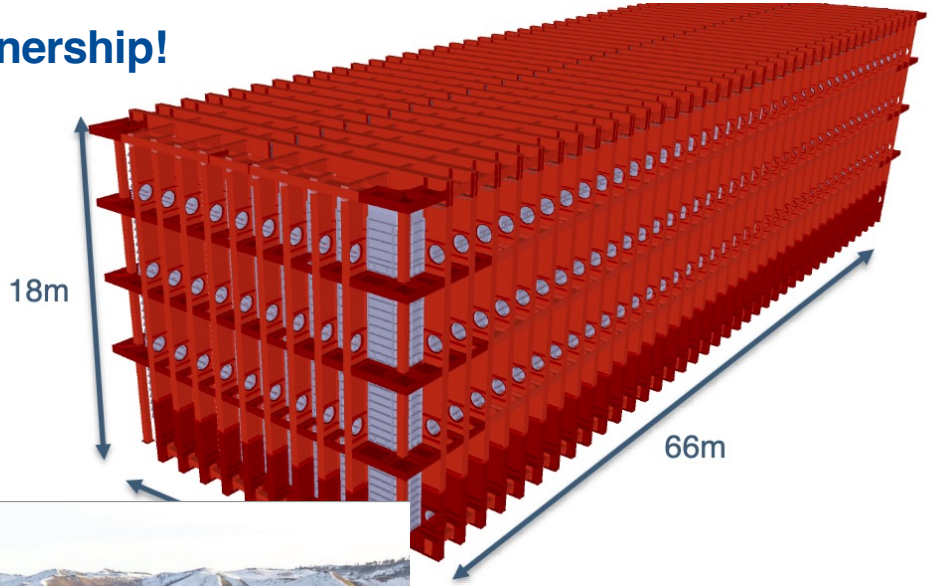
Excavation of Underground Facility in South Dakota is complete!

- **Excavation completed in Feb 2024!**
- > 800,000 tons of rock removed
  - equivalent of 8 aircraft carriers
- ~6500 cubic yards of concrete
- Work was done safely
  - Excavation subcontractor exceeded 1 million hours without a lost time incident. Significantly exceeded industry safety metrics.
- Cryostat installation begins in 2025



Far detector modules → International partnership!

CERN contributing the cryostats: constructed in Europe, shipped to South Dakota



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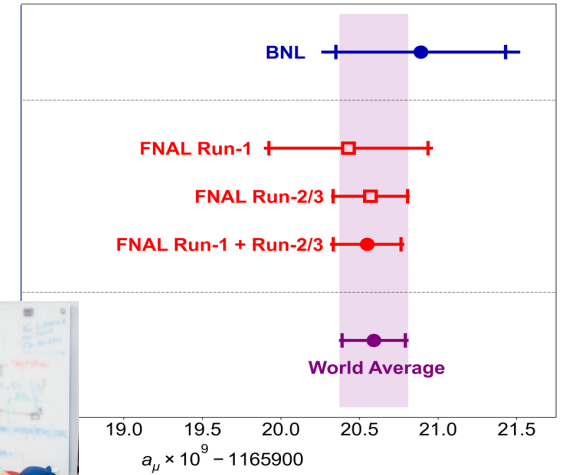
North Cavern

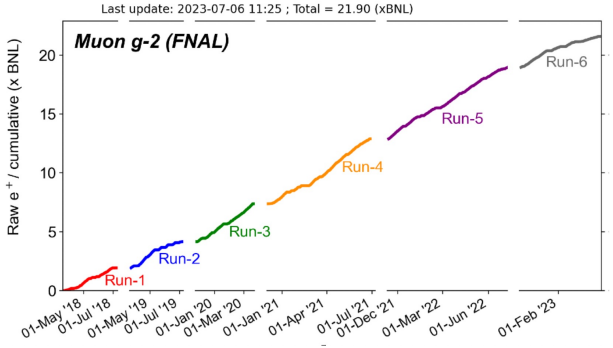

South Cavern

Intensity Frontier: Precision Science with Muons

Muon Science: g-2 outlook

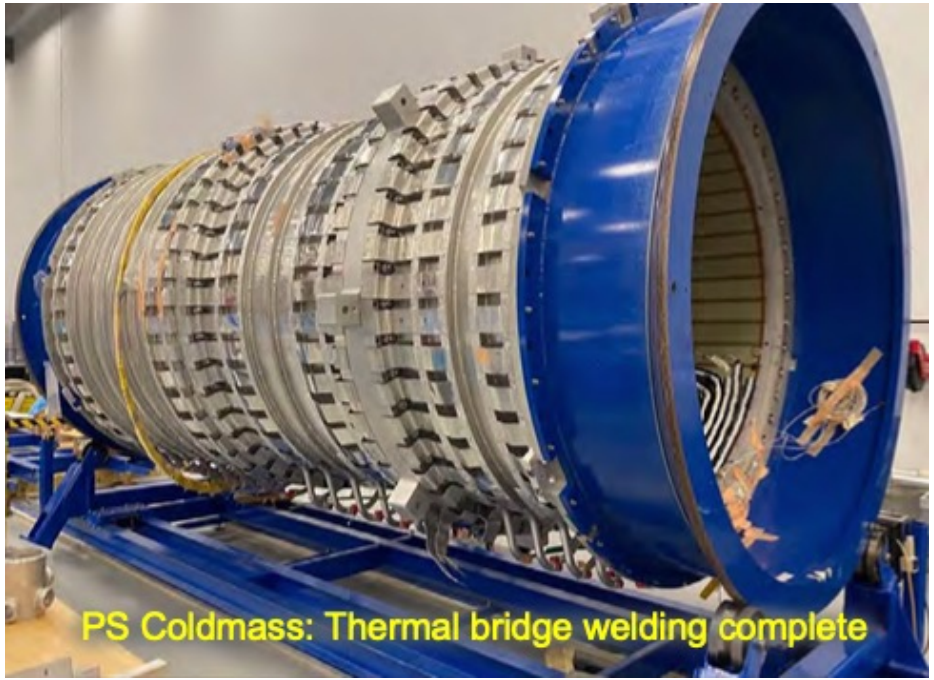
- **Second result from Run-2/3 data**
  - Second result garnered world-wide media attention with **2,000+ media mentions and 7+ billion media reach**
  - New average has **190 ppb** precision, dominated by FNAL
  - Systematic uncertainty of **70 ppb** already surpasses goal





- **Outlook**
  - Plan to **publish result of the full dataset in 2025** with twice improved statistical precision.
  - Jury is still out on theory predictions…

Mu2e Project: Looking for muon to electron conversion – if we see it – new physics at highest mass scales



Production Solenoid Cold Mass Assembly

1st Calorimeter disk instrumented

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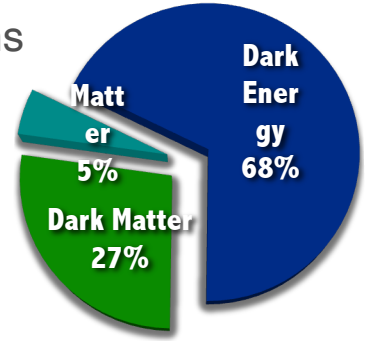
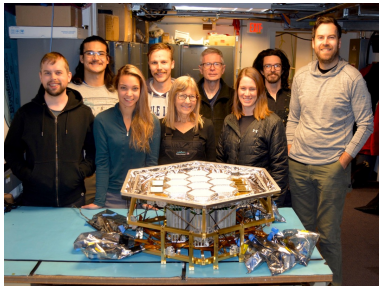
Cosmic Frontier

Cosmic Science

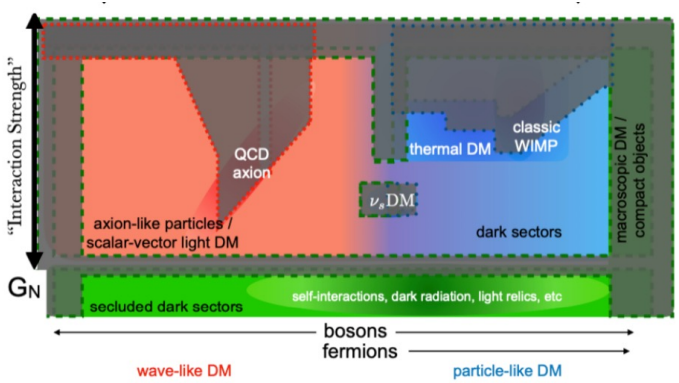
- The Cosmic Frontier addresses fundamental questions by connecting the very small to the very large:
  - **What is the dark matter?**
  - **What is dark energy?**
  - **What is the physics of inflation?**





SPT-3G Focal Plane at the South Pole

Aim high, search wide, delve deep



Dark Matter Parameter Space

Fermilab roles capitalize on unique strengths, core infrastructure, detector development support, facilities, and large talent pool

- Technical capabilities built up from accelerator program are applicable to cosmic experiments, including the **largest HEP investment in detector development**
- **Large pool of engineers and technicians**, all available to the user community

Fermilab

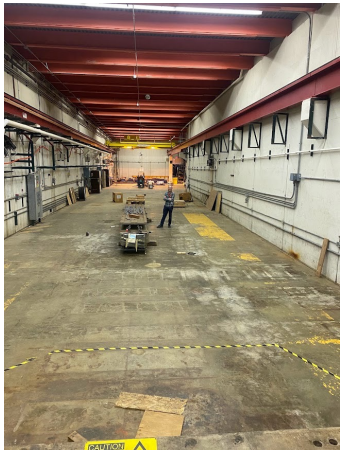
Dark Wave Lab (Axion Center for Dark Matter)

→ Build on facility for ADMX-EFR axion dark matter search
→ User facility for pathfinder experiments: prototypes to first measurements

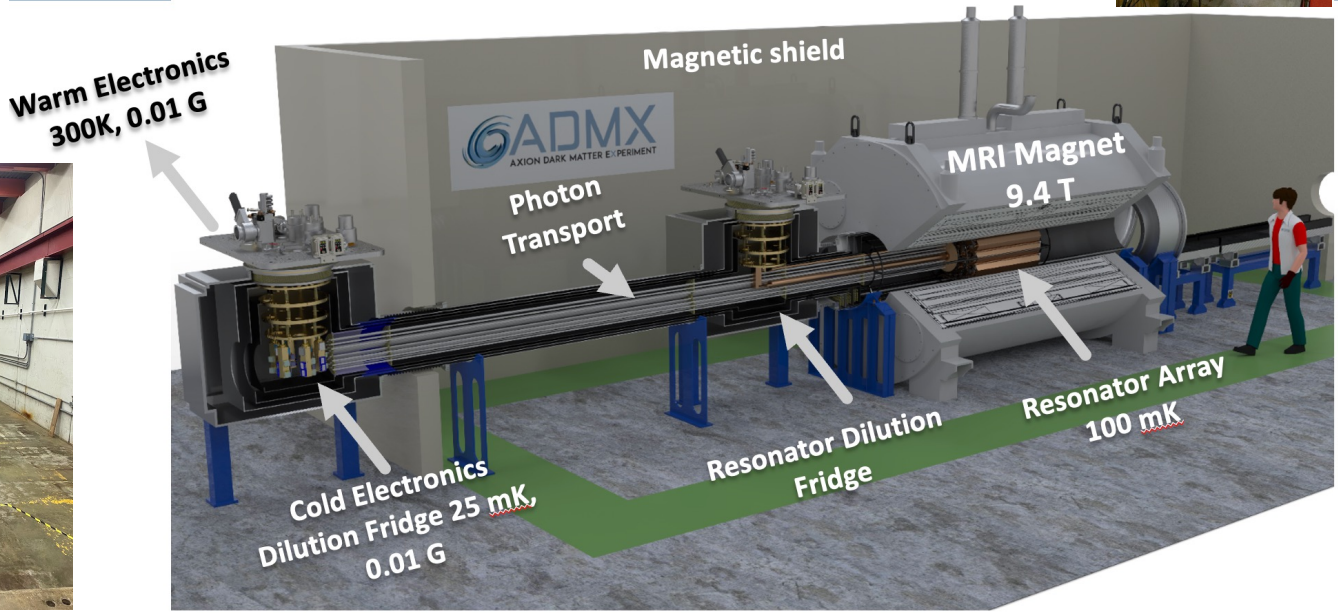
PW8/HIL at FNAL: Large, shallow underground hall with adjacent surface building. Total 13,000 square ft.

About half the space will be used by ADMX-EFR.

Expand for full Dark Wave Lab



ADMX-EFR Experiment Layout



Energy Frontier

Collider Science and the US CMS Collaboration

Collider Science

Vision: Fermilab continues to be the leading U.S. center for CMS and second leading center in the world after our partner CERN

- Fermilab is host lab for US CMS (27% of CMS)
- Fermilab LHC Physics Center hosts US CMS
- Execute HL-LHC AUP and CMS Detector Upgrade Projects
- **CERN is our European sister laboratory and our strong partner in many areas**

Fermilab's Patty McBride : CMS spokesperson

LHC Run 3 plan modified due to challenges encountered in 2023

CMS detector performed well in 2023 (92% efficiency in pp running – 29/fb recorded)

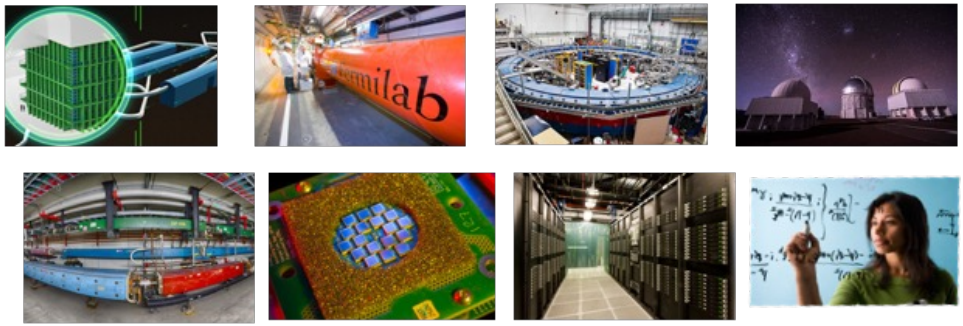
The LHC is currently in the year end technical stop (Expected start of commissioning in March 2024, physics data in April 2024)

CMS has published 1239 papers with collider data (highest # of publications from a single experiment), documenting innovative searches for new phenomena and precision SM measurements

Beyond the Frontiers

Fermilab and Emerging Technologies

HEP science with neutrinos, the LHC, muons, and the cosmos



Underpinned by strong competencies in accelerator and detector science and technology, computing, and theory

Our **science goals** demand ever increasing precision instruments, driving the need for **innovative techniques and technologies**

Many fundamental **HEP** research areas can **benefit** from emerging technology **applications** and many **HEP competencies** can help **advance new technologies**

Establishing new and rapidly advancing programs in **QIS** and **microelectronics**, leveraging national programs and initiatives. Continue to pursue **partnerships** to apply Fermilab **accelerator** and other technologies to new applications.

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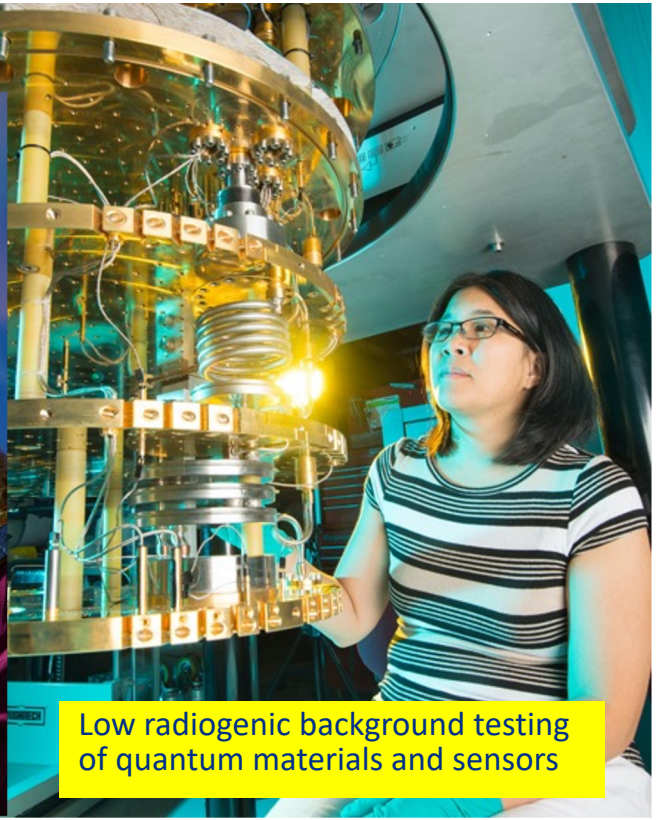
Quantum Science Center (QSC): Fermilab leads sensor and controls R&D

Science targets: Topological quantum materials/computing, single photon detectors, microcalorimetry for dark matter searches.
Engages condensed matter/materials capabilities of BES and ASCR.

highly multiplexed readout of cryogenic qubit/sensor arrays

Cryogenic qubit control systems



Low radiogenic background testing of quantum materials and sensors

Fermilab

Led by FNAL, $115M
Awarded August 2020

Superconducting Quantum Materials and Systems Center

A DOE National Quantum Information Science Research Center

24 Institutions
> 400 Researchers
> 100 students/postdocs

Fermilab · rigetti · Northwestern University · Ames Laboratory (Creating Materials & Energy Solutions, U.S. Department of Energy) · NASA Ames Research Center

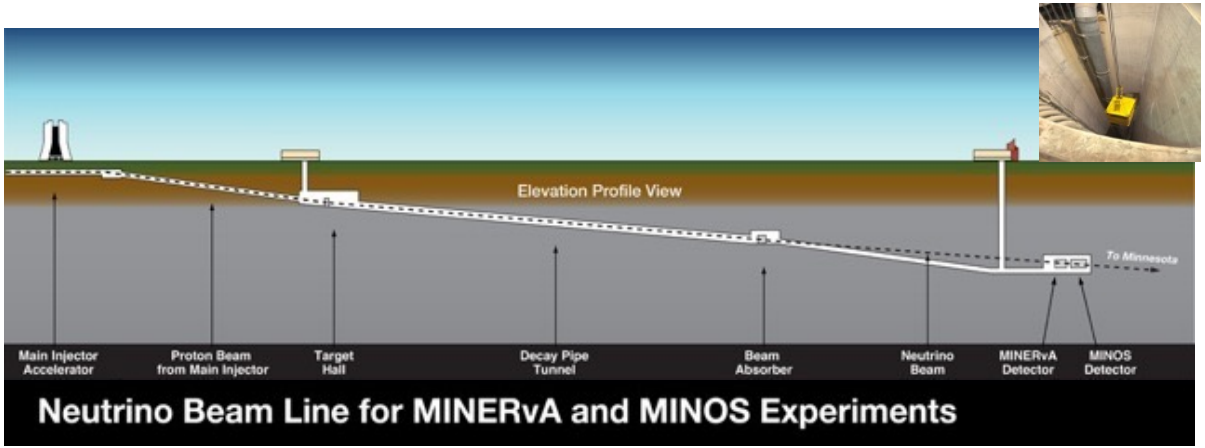
NIST · INFN Istituto Nazionale di Fisica Nucleare · Stanford University · University of Illinois Urbana-Champaign · Rutgers · Università di Pisa

University of Colorado Boulder · Illinois Institute of Technology · Johns Hopkins University · Temple University · Colorado School of Mines · The University of Arizona

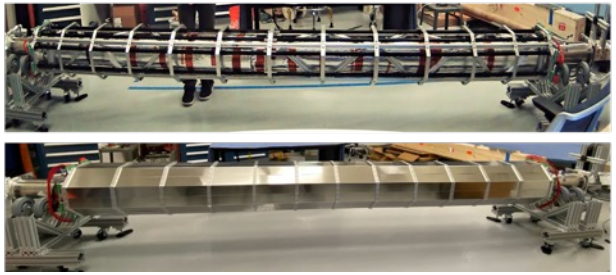
University of Minnesota · NYU · Goldman Sachs · LSU · Lockheed Martin · JANIS · Unitary Fund

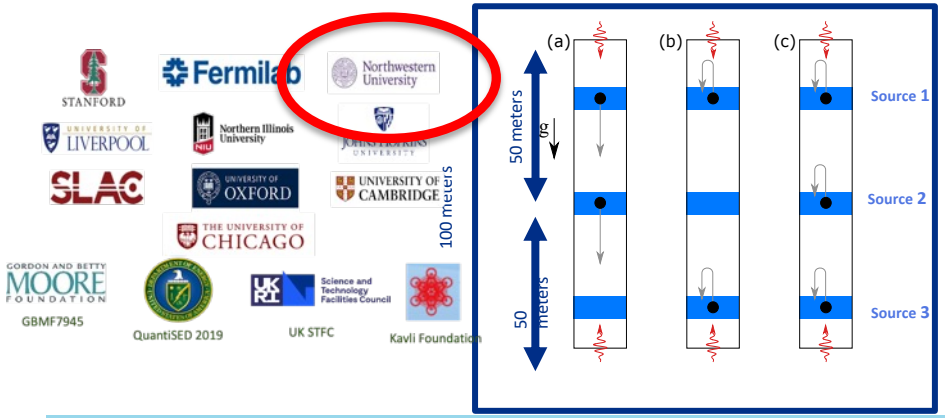
MAGIS-100 experiment at Fermilab

MAGIS-100 will explore fundamental physics using clock atom interferometry across a 100-meter vertical baseline.



Assembled prototype MAGIS module with horizontal bias coils and magnetic shield





- Major **technological advance** for studying very **low mass dark matter.**
  - 100 m baseline – order of magnitude better than current state-of-the-art
  - Uses ultra-precise Strontium clock transition.
- **Pathfinder** for longer baselines, sensitive to **~1 Hz gravitational waves.**

Take advantage!

05.28	**INTRO TO PARTICLE PHYSICS** Joshua Barrow | One West
05.30	**INTRO TO ACCELERATORS** Jeffrey Eldred | Curia II
06.04	**INTRO TO PARTICLE DETECTORS** Evan Niner | Curia II
06.06	**NEUTRINO PHYSICS** Meghna Bhattacharya | Curia II
06.11	**INTRO TO COSMOLOGY** Dan Hooper | One West
06.13	**Mu2e EXPERIMENT** Kevin Lynch | One West
06.18	**MUON PHYSICS AT FERMILAB/g-2** David Kessler | One West
06.20	**SEARCH FOR A THEORY OF EVERYTHING** Don Lincoln | One West

06.25	**QUANTUM COMPUTING** Hank Lamm | IARC Alvin Tollestrup Auditorium
06.27	**MAGIS-100 EXPERIMENT** Rob Plunkett | One West
07.02	**PARTICLE PHYSICS AT CMS** Karri DiPetrillo | One West
07.09	**ENGINEERING AT FERMILAB** Mayling L. Wong-Squires | Curia II
07.11	**INTRO TO SRF TECHNOLOGY** Jeremiah Holzbauer | Curia II
07.16	**MEDICAL PHYSICS APPLICATIONS AND AI** Maryellen Giger | One West
07.18	**BE SEEN: APPLYING FOR GRAD SCHOOL AND FELLOWSHIPS** Richard Wallace | One West

Welcome and Thank You for Coming!

- Fun facts
  - The top quark was discovered at Fermilab in 1995
    - Roughly **1 in 1,000,000,000,000** Tevatron collisions produced a top quark
  - The Higgs Boson was discovered at CERN in 2012
    - Supporting evidence from Fermilab (Tevatron)
    - Roughly **1 in 100,000,000,000,000** LHC collisions yielded a distinguishable Higgs Boson
  - The Muon g-2 experiment has measured the Muon “g-2” parameter to 0.20 parts per million
    - **g = 2.00233184110 +/- 0.00000000043 (stat.) +/- 0.00000000019 (syst.)**
  - Fermilab has about 200 PB of stored data
    - That’s **200,000,000 GB**
    - In **ten years, we will have 10x** the amount